A Comparative Study on Microgap of Premade Abutments and Abutments Cast in Base Metal Alloys

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The study compared the marginal accuracy of premade and cast abutments. Premade titanium, stainless steel, and gold abutments formed the control groups. Plastic abutments were cast in nickel-chromium, cobalt-chromium and grade IV titanium. The abutment/implant interface was analyzed. Analysis of variance and Duncan's multiple range test revealed no significant difference in mean marginal microgap between premade gold and titanium abutments and between premade stainless steel and cast titanium abutments. Statistically significant differences ($P < .001$) were found among all other groups.

Key Words: microgap, premade abutments, cast abutments, internal hex implant, screw loosening

INTRODUCTION

A dental implant system consists of an implant that is surgically implanted in the maxilla or mandible and an abutment that engages the implant. Depending on the specific system used, an abutment can include a mechanical connection mechanism within itself or can be clamped onto the implant by means of an abutment screw. The dental prosthesis is then fabricated over the abutment.[1] The connection of the abutment to the restorative interface of the implant creates a space called a microgap. The vertical microgap between the implant and the abutment plays a crucial role in implant survival and prosthetic success. The microgap may be colonized by bacteria and cause inflammatory reaction in peri-implant hard and soft tissue.

An absolutely precise fit (passive fit) between the prosthesis framework and abutments has been advocated to avoid stress concentrations in the bone adjacent to the implants.[2–4] From a mechanical engineering standpoint, discrepancies and microgaps between components are inevitable when different parts are fitted together.[5] According to the current scientific evidence and the efficacy of contemporary dental technology used for framework fabrication, it has been concluded that an absolute passive fit cannot be obtained.[6] If an absolute passive fit cannot be obtained between implant/abutment interfaces, this may lead to such prosthetic complications as loosening or fracture of the screws that retain the prosthesis to implant.[7–11] Fracture of abutment screws is more prevalent than fracture of prosthesis-retaining screws.[12–14]

A clinical trial carried out by Jemt and Book[15] could not find a statistically significant correlation between marginal bone level and prosthesis misfit. But when considering the mechanical aspect of the implant prosthesis, poor fitting prosthesis with 6 μm to 10 μm vertical misfit may lead to screw loosening.[11,15]

Previously, a few in vitro studies have reported on the marginal fit and size of microgaps at the implant abutment interface for external hex joint-

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type implants. Binon[16] reported a marginal error of 49 μm for the Branemark implant, including the rounded edge of the abutment. Dellow et al[17] reported mean vertical discrepancies that ranged from −79.3 μm to 24.3 μm. In addition, Byrne et al[18] reported external vertical discrepancies that ranged from 36 to 86 μm, and horizontal discrepancies that ranged from −66 μm to 11 μm. Kano et al[19] also reported marginal fit of implant abutment interface and the following mean values for vertical, horizontal, and gap depth, respectively: 4.13 μm, 14.5 μm, and 6.93 μm for premade silver-palladium cylinder; 23.18 μm, 33.2 μm, and 88 μm for cast nickel-chromium (Ni-Cr) cylinder; and 25.6 μm, 51.8 μm, and 114.54 μm for cast cobalt-chromium (Co-Cr) cylinder.

Jemt et al[20] showed a 49% rate of screw failure for the maxilla and 20.8% for the mandible, accounting for 13% of prosthesis mobility. Zarb and Schmitt[21] examined 274 implants and noted 9 abutment retaining screw fractures and 53 gold alloy screw fractures during a 4- to 9-year period of observation. Jemt[3] reported that in a population of 373 edentulous patients receiving 391 prostheses, 42% of the maxillary and 27% of the mandibular prostheses exhibited unstable gold screws at the 2-week postplacement appointment.

Tolman and Laney[13] provided results from 407 jaws, both edentulous and partially edentulous, and cited the most frequent mechanical complication as screw fracture (both gold and abutment screw), which mainly occurred in mandibular prostheses between the second and fourth years of service. Similar complications in patient populations receiving overdenture prostheses have been reported by Naert et al,[22] who stated that loose gold screws in mandibular overdentures occurred in 5% of 86 consecutively treated patients. An estimate of the clinical problem in partially edentulous patients treated with implants was provided by 2 additional reports, which also suggested that loose gold screws were the most common mechanical problem in this patient population.[19,22]

The amount of freedom between the implant hexagonal extension and its abutment counterpart has also been implicated as a factor in screw joint instability.[23,24] Binon[25] suggested that, in the presence of poor fit and a lack of rotational resistance between the hexagons, a rotation and/or displacement in the x-y axis could occur during function. He reported that fit tolerance is a major factor in such a phenomenon.

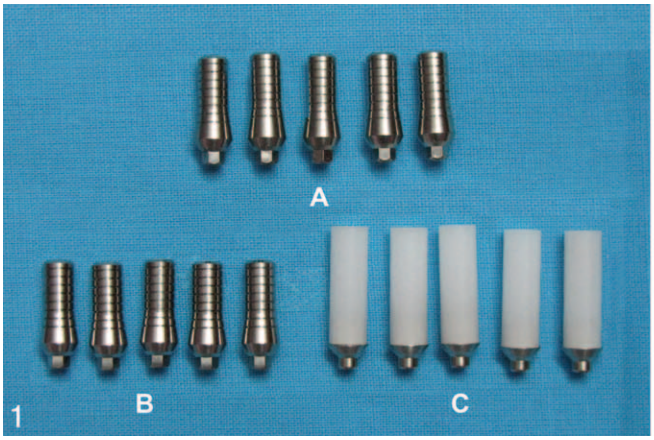
Another variable influencing joint stability is how the contacting parts change when the screw is tightened.[26] Distortion of both the superstructure and the implant is observed during the tightening of a screw-retained superstructure.[27] Measurement of the exact 3-dimensional distortion of a framework (the marginal discrepancy) is a difficult task. Jemt and coworkers[28] also reported that there was a 3-dimensional distortion of the gold cylinders ranging between 3 μm and 80 μm and that there was no significant difference between the fit of cast and computer numeric controlled-milled frameworks and the lack of passive fit.

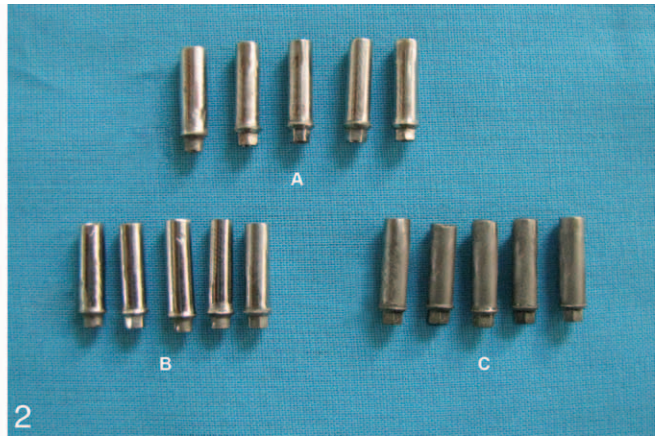
According to McGlumphy et al,[29] screw loosening occurs when the joint-separating forces acting on the screw joint are greater than the clamping forces holding the screw unit together. Excessive forces cause slippage between threads of the screw and threads of the bore, resulting in a loss of preload.[30]

To improve or even ensure a better fit, the use of premade components has been highly recommended. The high cost of this type of framework has led to the development of plastic components allowing the use of alternative alloys, like base metal alloys.[19] The purpose of the present study was to compare the marginal accuracy between internal hex implant with internal bevelled platform and abutment fitting surface obtained by plastic components cast with 2 chromium type alloys (Ni-Cr and Co-Cr) and grade IV titanium and the marginal fit of premade standard abutments made of grade V titanium, stainless steel and gold.

Materials and Methods

All study components were manufactured by MIS Implants Technologies Ltd (Shlomi, Israel). The following components were used in this study: a 4.20 mm (diameter) × 16 mm (length) internal hex implant (manufacturer code MF7-16420); a torque wrench (MT-R1040); 10 cementable premade standard abutments. of which 5 were made of grade V titanium and 5 were made of stainless steel (manufacturer code MD-MAC10); 5 premachined standard gold abutments with plastic sleeve (manufacturer code MD-GP010); and 15 plastic abutments (manufacturer code MD-CPH13), of which 5





Figures 1 and 2. Figure 1. Premade abutments for implant. (a) Premade standard abutments made of grade V titanium. (b) Premade standard abutments made of stainless steel. (c) Premachined standard gold abutments with plastic sleeve. **Figure 2.** Cast abutments. (a) Cast nickel-chromium abutments. (b) Cast cobalt-chromium abutments. (c) Cast grade IV titanium abutments.

were cast using Co-Cr type alloy, 5 with Ni-Cr type alloy, and 5 in grade IV titanium. The precision milled metallic abutments formed the first 3 groups, which were used as the control groups. A sample size of 5 abutments was selected.

Premade standard abutments (Figure 1) and cast abutments (Figure 2) were divided into the following groups: group 1 comprised 5 cementable premade standard abutments made of grade V titanium, group 2 comprised 5 cementable premade standard abutments made of stainless steel, group 3 comprised 5 premachined standard gold abutments with plastic sleeve, group 4 comprised 5 cast Ni-Cr abutments, group 5 comprised 5 cast Co-Cr abutments, and group 6 comprised 5 cast grade IV titanium abutments.

The cast specimens for groups 4 and 5 were produced using the plastic cylinders that were invested in phosphate bonded investment (A-Vest CB, Adentatec GmbH, Koeln, Germany) and specimens for group 6 were invested in silica bonded investment (Titec GMG, Orotig, Verona, Italy), according to the manufacturer's recommendations. Each component for group 4 and group 5 was invested and then cast individually, in an automatic pressure casting machine (Argon pressure casting machine, Reital, Reitel, Bad Essen, Germany) and the components of group 6 was also invested and cast individually in an automatic titanium casting machine (Titec F205M, Orotig, Verona, Italy). A pressure of 4 bars was used to cast each specimen in both of the casting machines. After bench cooling and careful devesting, the casted specimens were retrieved. The specimens were sandblasted using alumina to remove the investment clinging to the casting. Sprues were cut and the specimens were steam cleaned and later kept in distilled water for 60 seconds in an ultrasonic cleaner. No further finishing and polishing procedure was performed. Alloy composition and melting range of alloys are listed in Tables 1 and 2.

One internal hex implant was embedded in an acrylic resin model (DPI-RR Cold Cure, Dental Products of India, Delhi, India) of hexagonal shape (3.0 cm $\times$ 1.6 cm $\times$ 1.6 cm). Using the torque wrench each standard and cast abutment was tightened to 35 Ncm on the internal hex implant. Following the initial torquing, each sample was again retightened to 35 Ncm after a period of 10 minutes.

Testing the specimens

The implant-abutment interface for each specimen studied was analyzed at 6 different locations around the implant/abutment interface, according to the resin model design, using OGP SmartScope CNC500 Measuring System (OGP Inc, Rochester, USAmanufacturer's name, city, country/state) under 295$\times$ magnification.

Samples were scanned using a high-sensitivity charge coupled device camera (OGP Inc, Rochester, NY). The equipment had a measuring range (XYZ) of 500 $\times$ 450 $\times$ 200 mm, scale resolution of 0.5 μm, and XY accuracy of $E_2 = (2.5 + 5\ L/1000)\mu m$, in which L = measuring length in millimeters. A total of 180

TABLE 1

Alloy composition and melting range of Ni-Cr and Co-Cr type alloys*

Alloy Type	Ni	Cr	Co	Mo	Si	Others	Melting Range (°C)
Wiron 99†	65	22.5		9.5		Nb, Si, Fe, Ce	1250–1310
Wironit†		28.6	64	5	1	Mn, C	1320–1350

*Ni indicates nickel; Cr, chromium; Co, cobalt; Mo, molybdenum; Si, silicon, Nb, niobium; Fe, iron; Ce, cerium; Mn, manganese; C, carbon.
†BEGO, Bremer Golds Goldschlägerei Wilh.Herbst GmbH & Co. KG, Bremen, Germany.

readings and images of the abutment-implant interface around the specimens were taken and used for analysis (Figure 3a through f).

Statistical analysis

Data were analyzed using the Statistical Package for Social Sciences software (SPSS Statistics for Windows Version 20.0, SPSS, Inc, Armonk, NY). One-way analysis of variance (ANOVA) was performed as a parametric test to compare different groups. Duncan's multiple range test was also performed as post hoc analysis enabling multiple comparisons. For all statistical evaluations, a two-tailed probability of $<.05$ was considered significant.

Results

One-way ANOVA was performed as a parametric test to compare the different groups. Table 3 lists mean value, standard deviation, standard error, confidence interval for the mean, F value, and significance.

Duncan's multiple range test was also performed as a post hoc analysis enabling multiple comparisons. It depicts mean, standard deviation, F value, and *P* value. For all statistical evaluations, a two-tailed probability value $<.05$ was considered significant.

Statistical analysis revealed that there was no statistically significant difference in the mean marginal microgap between group 1 and group 3 and between group 2 and group 5. Statistically significant differences ($P < .001$) were found among all other groups. Results of the comparison of mean marginal microgap in micrometers for various milled and cast abutment groups are shown in Figure 4.

Discussion

The original protocol in implant prosthodontics recommends the use of a gold framework for prostheses. However, because of their high cost, base metal alloys were introduced for manufacturing premade abutments and producing cast abutments. The use of base metal alloys in conventional prosthodontics is widely accepted because of the improved properties of these alloys and because of their low cost compared with that of gold alloys. More than 80% of dentists in the United States use base metal alloys containing nickel, chromium, and beryllium in their prosthodontic practice.[31]

Conventionally in implant prosthodontics, framework manufacture consists of casting-on to prefabricated gold alloy cylinders. For the overcasting technique, the casting alloys must be chosen on the basis of the thermal properties relative to the cylinders, and the temperature of a cast molten alloy should not closely approach the solidus temperature of the cylinder. Usually, metal premade cylinders are made of gold or silver-palladium alloy with a melting range around 1280°C to 1350°C; therefore, the chosen casting alloys should not have a liquidus temperature higher than 1000°C.[32] Because Ni-Cr and Co-Cr alloys have a melting range around 1200°C and 1315°C, they should not

TABLE 2

Alloy composition and melting range of grade IV titanium

Alloy Type	Nitrogen	Carbon	Hydrogen	Iron	Oxygen	Titanium	Melting Range (°C)
Grade IV titanium	0.01	0.01	0.001	0.24	0.27	99.469	1670

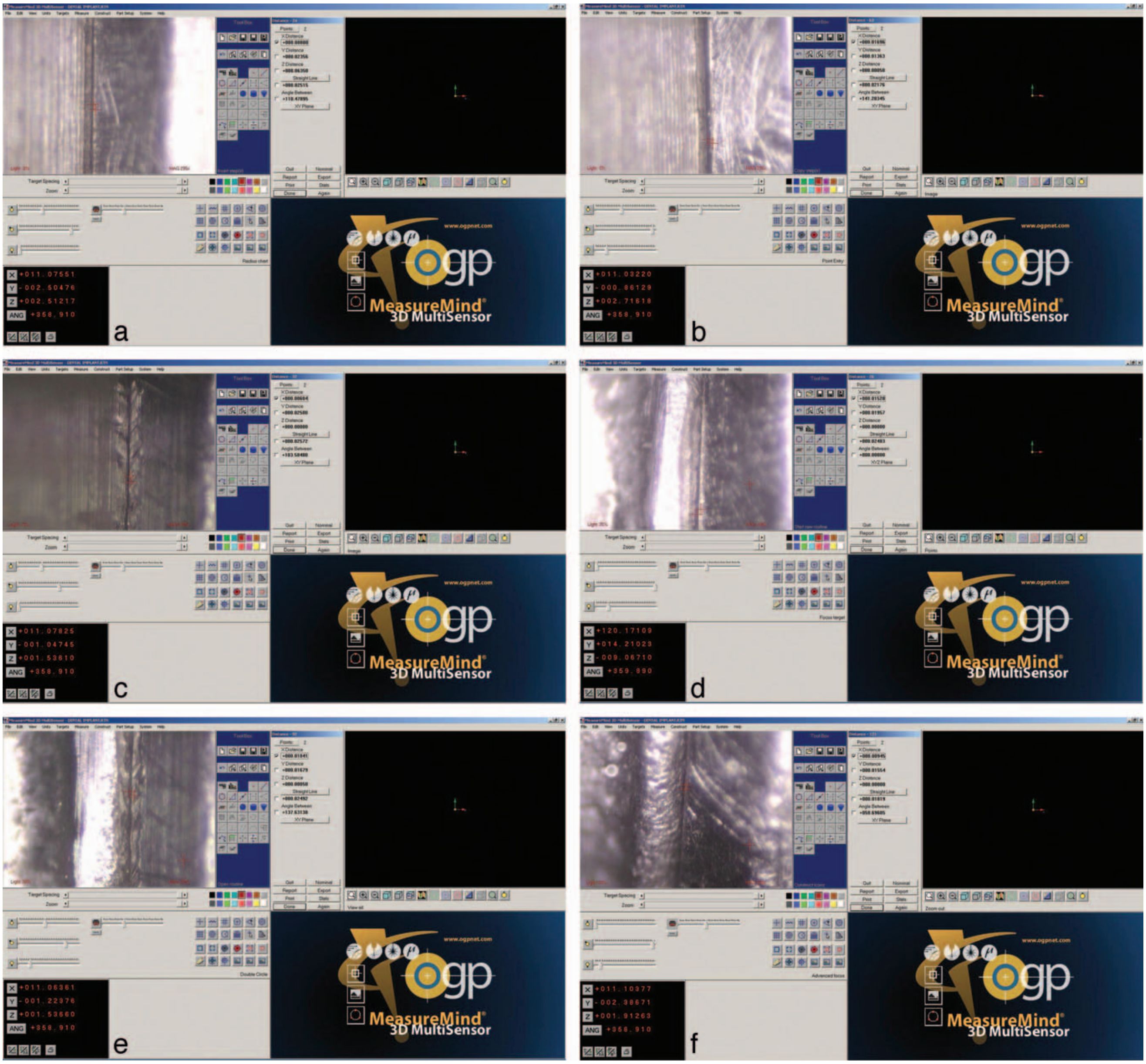
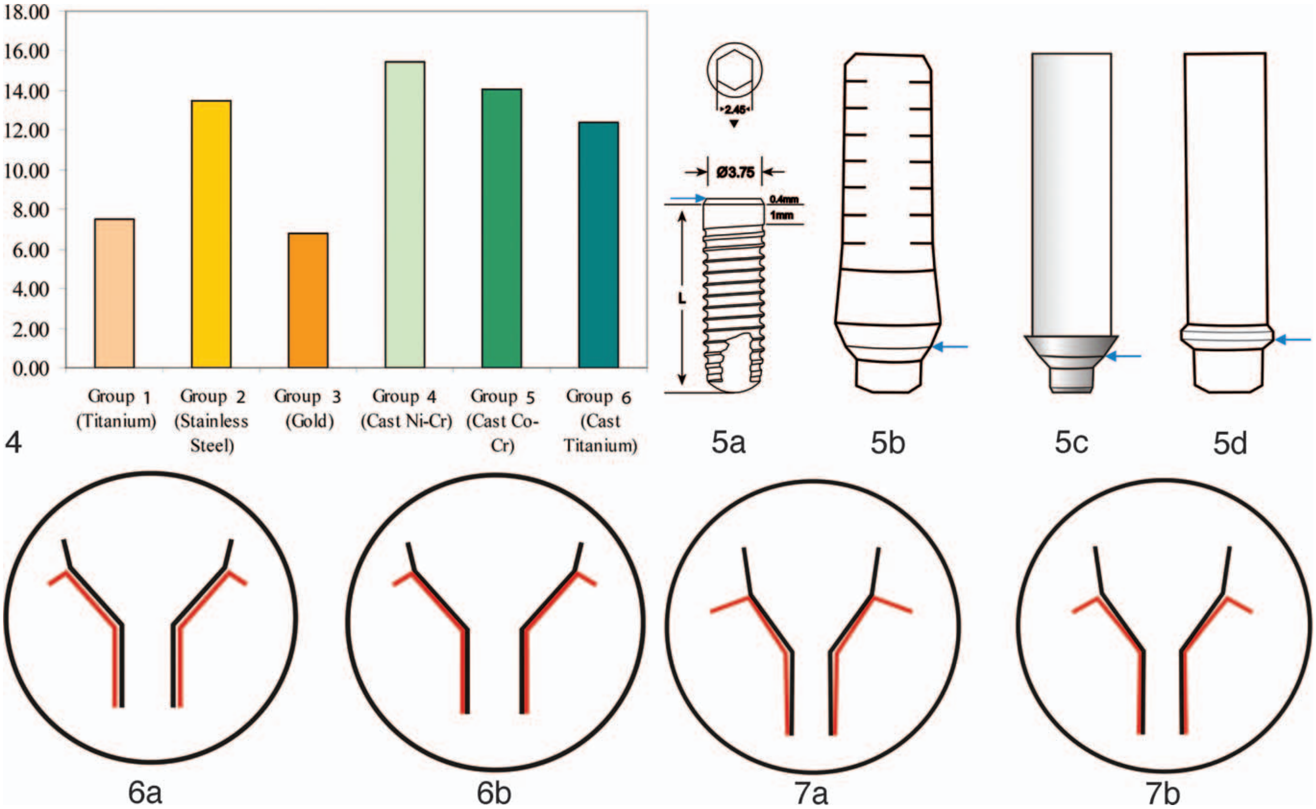


FIGURE 3. (a) Scanned image of the interface between implant and premade titanium abutment. (b) Scanned image of the interface between implant and premade stainless-steel abutment. (c) Scanned image of the interface between implant and premachined standard gold abutments with plastic sleeve. (d) Scanned image of the interface between implant and cast Ni-Cr abutment. (e) Scanned image of the interface between implant and cast Co-Cr abutment. (f) Scanned image of the interface between implant and cast grade IV Titanium abutment.

be used with premade gold cylinders. Plastic cylinders are the only available option if this type of alloy is used.[19] This study compares the marginal accuracy of premade cylinders versus plastic cylinders cast with 3 different base metal casting alloys.

When plastic cylinder components are used, the conventional lost wax technique is used and the contact surface of the cylinder as well as the internal cylinder surface are influenced by a variety of processing and handling conditions of the fabrication process and by the casting accuracy of the alloy.[33] Statistical analysis for the present study revealed that no significant difference exists in the mean marginal microgap between group 1 and group 3 and between group 2 and group 5. The study, however, showed that marginal discrepancies for cast components obtained from plastic cylinders were statistically higher than for premade cylinders made of gold and grade V titanium.

In a previous study, Kano et al[34] compared the



Figures 4–7. Figure 4. Comparison of mean marginal microgap in micrometers for various milled and cast abutment groups. **Figure 5.** Schematic line diagrams of the specimens. (a) The internal hex implant and standard platform. The arrow points to the first reference bevel for measuring the vertical gap. (b) Premade titanium/ stainless steel abutment with arrow pointing to the second reference bevel for measuring the vertical gap. (c) Premachined standard gold abutment with arrow pointing to the second reference bevel for measuring the vertical gap. (d) Plastic abutment/cast abutment with arrow pointing to the second reference bevel for vertical gap measurement. **Figure 6.** (a) Process of approximation of implant and abutment. (b) Ideal approximation of the implant and abutment. **Figure 7.** (a) Bevels present on the standard platform and fitting surface of abutment contacts on their superior aspect. (b) Bevels present on the standard platform and fitting surface of the abutment contact on their inferior aspect; a gap exists on the superior aspect.

vertical misfit obtained after casting procedures when plastic cylinders and gold cylinders were used. Higher values were obtained for all groups compared with the findings in the present study. In another study, Kano et al[19] compared the microgap between cast base metal cylinders and external hex premade cylinders and obtained higher values for all groups compared with the present study. All of these studies clearly demonstrate that casting procedures do influence the final fit of prosthetic components when plastic cylinders are used, no matter what type of alloy is used. The inability to produce a surface free of irregularities and the impossibility of finishing and polishing the final

Table 3

One-way analysis of variance comparing different groups*

Group	Mean	SD	F Value	*P* Value
Group 1 (titanium)	7.51[a]	1.88	82.624	<.001
Group 2 (stainless steel)	13.51[c]	2.21		
Group 3 (gold)	6.75[a]	1.71		
Group 4 (cast Ni-Cr)	15.48[d]	2.79		
Group 5 (cast Co-Cr)	14.06[c]	2.42		
Group 6 (cast titanium)	12.38[b]	1.90		

*Means with same superscript letter do not differ from each other according to Duncan's multiple range test.

surface with reliability may be another reason for the discrepancies observed. The initial fit of plastic cylinders can be responsible for the results obtained because even premade metal cylinders present a marginal misfit. Marginal discrepancies of the as-received metal cylinders can vary from 0.5 μm to 5.04 μm, depending on the implant system used, and as high as 46.9 μm when components from different manufacturers are combined.[35] However, in a retrospective study, Kallus and Bessing[11] claimed that 236 patients wearing a misfitting implant-supported prosthesis for at least 5 years had no signs of loss of osseointegration and that misfit of the superstructures did not affect the maintenance of marginal bone level. It seems that the biological response for misfit levels between 38 μm and 345 μm is similar.[36]

The difference in mean marginal microgap found in the present study among the 3 base metal alloys may be attributed to castability, casting shrinkage, and the use of pressure casting technology and automatic casting machines. The density values of base metal alloys are approximately half those of the casting gold alloys. For this reason the thrust developed during casting may be somewhat lower, and it is possible that the casting may not adequately fill the mold. Casting machines used for base metal alloys must therefore be capable of producing an extra thrust that overcomes this deficiency.[37] Newer, automatic-pressure casting machines are probably more efficient in producing this extra thrust. According to Moffa et al,[38] increasing the casting temperature increases the flow of the alloy and reduces casting failures; nevertheless, it also increases surface roughness, which poses additional difficulty in the finishing and polishing procedures. The influence of alloy type on marginal fit values observed in this study was not so pronounced as for fixed partial dentures. Compared with the geometry of the finish line of the prepared teeth, the more regular cylinder-abutment joint provides uniform deposition of wax around the margins. The hypothesis is that there is less chance of producing areas with different shrinkage patterns.[39] Byrne et al[18] assessed the adaptation of premachined, cast, and laboratory modified premachined abutments to implants at 2 sites: abutment/implant interface and screw to screw seat. They found that the adaptation of abutments to implants was closer and the amounts of contact larger for assemblies with premachined and laboratory-modified premachined abutments than for those with cast abutments. Although gold alloys have lower casting shrinkage than Co-Cr alloys, 3-year clinical results of Co-Cr frameworks are promising.[40]

Passive fit is assumed to be one of the most significant prerequisites for maintaining implant-bone interface. To provide passive fit or a strain-free superstructure, a framework should induce absolute zero strain on the supporting implant components and the surrounding bone in the absence of an applied external load. This vital requirement may be provided by simultaneous and even mating of the complete inner surfaces of all retainers by abutments. It was found that poor fitting prosthesis with 6 μm to 10 μm vertical misfit may lead to screw loosening.[11,15] It has been concluded that if an absolute passive fit cannot be obtained between implant/abutment interfaces, this may lead to prosthetic complications such as screw loosening or fracture related to poor framework fit.[41] An absolutely precise fit (passive fit) between prosthesis framework and abutments has been advocated to avoid stress concentrations in the bone adjacent to the implants.[2,3,4] The microgap may be also colonized by bacteria and cause inflammatory reaction in peri-implant hard and soft tissue.

Mechanical considerations

In this study, 30 implant abutments were divided into 6 groups: group 1 comprised 5 cementable premade standard abutments made of grade V titanium, group 2 comprised 5 cementable premade standard abutments made of stainless steel, group 3 comprised 5 premachined standard gold abutments with plastic sleeve, group 4 comprised 5 cast Ni-Cr abutments, group 5 comprised 5 cast Co-Cr abutments, and group 6 comprised 5 cast grade IV titanium abutments. The precision milled premade abutments were used as controls. Schematic line diagrams of the various components used for this study are given in Figure 5.

Whenever an abutment is tightened on an implant with internal hex standard platform, the ideal expected vertical gap is zero, with uniform contact between the entire contacting surfaces (Figure 6). However, to enable the abutment to enter the standard platform of the internal hex implant, the milling process should incorporate a tolerance for this. This results in a milling of the abutment fitting surface that is a little smaller than the implant platform in micrometer level. Hence, the implant standard platform and the engaging fitting surface of the abutment will be different dimensions.

The present study found that the mean marginal microgap for cast abutments was 15.48 μm for Ni-Cr, 14.06 μm for Co-Cr, and 12.38 μm for grade IV titanium and for the premade cylinders was 7.51 μm for grade V titanium, 13.51 μm for stainless steel, and .75 μm for gold.

The major reason for this deviation from normal may be the milling procedure. It is extremely difficult to precisely control the milling procedure at a micrometer level. From a mechanical point of view, it is clear that no two beveled, milled surfaces can be exactly the same. Discrepancies and microgaps between components are inevitable when different parts are fitted together. Lack of uniform contact between the implant and abutment interface, however, may lead to tilting and rocking of the abutment and thereby prosthesis failure. When the implant and abutment are tightened under 35 Ncm, milliing can result in the types of configurations shown in Figure 7.

Both of these configurations can result in screw loosening and microbial colonization. Depending on the location of contact among the bevelled surfaces, the vertical gap or microgap and the area of contact between the implant and abutment vary. The lack of contact between both components may lead to tilting and rocking of the final restoration, which may cause screw loosening and fracture. However, when the bevels meet on their superior aspect, it reduces tilting and rocking compared that of bevels that meet on their inferior aspect.

When a clinician applies a torque to a screw to tighten the components together, the tightening torque develops a force within the screw called the preload. The preload is determined by the applied torque and other factors, such as the screw alloy, screw head design, and abutment surface. The established preload is proportional to the applied torque. Increasing the torque will increase the preload. Increasing the preload maximizes the stability of the screw joint by increasing the clamping threshold that separating forces must overcome to cause screw loosening. Once external forces exceed the screw joint preload, the joint becomes unstable. The external load rapidly erodes the preload, resulting in vibration and micromovement, which lead to screw loosening. Excessive forces cause slippage between threads of the screw and threads of the bore, resulting in a loss of preload.[30]

Screw loosening may be an early warning of inadequate biomechanical design or occlusal overloading.[26] Whenever there is a vertical microgap between the implant and the abutment, this can also result in decreased transfer of preload, thereby hastening the process of screw loosening. In addition to this, in implants using screws the biting force lowers the pre-tension in the screw. A combination of nonuniform contact between implant-abutment interfaces, coupled with greater loading than the installed forces, enhances screw loosening.

Changes in the surface of the cylinder can influence preload because the torque is influenced by friction of this area, and part of the preload can be lost when the screw is used to bring the components together. After being tightened together by the screw, the microroughness of all the metal contacting surfaces slightly flattens and the microscopic distance between contacting surfaces decreases. As a result of this process, called "settling," the screw loses part of its preload.[42]

To reduce the settling effect, implant screws should be retightened 10 minutes after the initial torque application.[8,43,44] Siamos et al,[44] as a result of an in vitro investigation, also suggested that retightening abutment screws 10 minutes after initial torque application should be routinely performed. The investigators also reported that increasing the torque values for abutment screws above 30 Ncm can be beneficial for abutment-implant stability and to decrease screw loosening.

Once the screw is tightened, friction is important to secure the joint, and in an internal connection with an inner tapered abutment, friction between the taper interfaces contributes to joint stability.[45–48] Vigolo et al[49] assessed the precision at the implant interface of gold machined University of California Los Angeles (UCLA)-type abutments and computer-aided design/computer-aided manufacturing (CAD/CAM) manufactured titanium abutments with both external hexagonal connection and internal hexagonal connection. It was found that both types of abutments (gold machined UCLA type and CAD/CAM) consistently showed one degree of rotational freedom between the implant and abutment in cases of external hexagonal connection and internal hexagonal connection.

The reduction in metal cylinder hardness after the casting procedures can also allow plastic deformation under external loads and a reduction in screw tension. For plastic cylinders, alloy selection could alter the hardness of cast cylinders and influence preload.[50] Screw tightening causes strains in and around dental implants, and its magnitude depends on the amount of misfit.[51,52] Distortion of both the superstructure and the implant is observed during the tightening of a screw-retained superstructure.[27] In such cases, the amount of distortion may reach a level such that a 500-μm marginal gap may not be detectable with an explorer.[52] A subtle closure of gaps occurs. Prestresses in the entire system may cause complications associated with cyclic fatigue under continual application of functional loads over time. Previously, it has been shown that preload is significantly reduced when abutment components are cast, and this influence can be minimized if the contacting surface is finished and polished.[49]

Great variables are encountered in the use of plastic components to fabricate implant superstructure. Use of plastic abutments to produce cast abutments may be economical; however, the use of plastic abutments should be viewed with caution when precision and predictability are desired. Longitudinal clinical studies are required for providing a conclusive opinion on this issue.[19]

Clinical implications and significance

Successful dental implantation and thereafter prosthetic loading require a high degree of precision regarding the implant platform and the engaging abutment portion. The premade abutments, especially the gold frameworks, show better marginal accuracy compared with cast abutments. However, their high cost limits their use for most rehabilitative procedures. This justifies the use of base metal alloys to cast plastic components. Nonetheless, their use should be viewed with caution because of the higher occurrence of microgaps.

Limitations of the study

Cross-sectional studies are required to establish a conclusive opinion regarding the marginal microgap and the nature of the abutment-implant interface. However, such a procedure was not included with the present methodology because of time constraints.

Conclusions

Within the parameters of this in vitro study and its limitations, the following conclusions can be made:

- The marginal microgap of premade gold abutments and premade grade V titanium abutments are of an acceptable level.
- The premade stainless steel and all cast abutments showed more marginal inaccuracies than is acceptable.
- Among the cast abutments, the cast titanium abutments showed higher marginal accuracy, followed by cast Co-Cr abutments and cast Ni-Cr abutments.
- Compared with cast titanium abutments, the premade stainless steel abutments were less accurate.

Abbreviations

ANOVA: analysis of variance
CAD/CAM: computer-aided design/computer-aided manufacturing

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